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Comprehensive overview of renewable energy development in Taiwan

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ABSTRACT

As world population continues to grow, fossil fuels keep decaying and global warming becomes a serious problem, hence meeting the demand of energy is becoming a challenge. After the Fukushima accident in March 2011, more and more people are against the operation of nuclear power plants in Taiwan. Taiwan government has also recognized the increasing need for energy independence, and has passed relevant acts and regulations to promote renewable energy. The purpose of this paper is to provide an overview of renewable energy development in Taiwan. Current conditions and future prospects of six types of renewable energy in Taiwan are discussed: wind energy, ocean energy, solar energy, biomass energy, geothermal energy and hydropower energy. The findings show that solar thermal energy, photovoltaics and wind energy are the most promising renewable energy sources in Taiwan because of Taiwan's geographical characteristics and technological advantages acquired in the related industries.

Contents

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1. Introduction

Taiwan's total energy consumption has increased substantially over the past two decades, from 53.25 million kiloliters of oil equivalent in 1991 to 111.92 million kiloliters in 2011 with an average annual growth of 3.78% [1]. Carbon dioxide (CO_2) emissions from the consumption of energy in Taiwan were 293 million tons in 2011, accounting for 0.9% of the global emission [2]. The annual growth rate of CO_2 emissions in Taiwan is more than 5% over the past 20 years, ranking 23rd on the global list and 6th in Asia and Oceania [2]. Correspondingly, CO_2 per capita emission in Taiwan was 6.2 t in 1990 and increased to 12.654 t in 2011, ranking 27th on the global list [2]. Taiwan, a newly industrialized country with 22 million people residing on an island of 36,000 km^2, has faced a number of energy utilization challenges. First, over 99% of total energy supply comes from imported fossil fuels [3]. Availability of imported energy supplies and fluctuations in international energy prices strongly impact on the economic development in Taiwan. Second, facing future sanction from Tokyo Climate Protocol, Taiwan is in a crucial transition period of sustainable development of economy and society [4]. Specifically, Taiwan, relying heavily on energy, foreign trade and manufacturing, must confront the transition to a low-carbon economy and society [5]. Third, the dependence and inflexibility of regional power supplies during natural disasters such as earthquakes and typhoons is a big problem since the concentrated power supply system is connected only by two main transmission lines.

The Taiwan government has implemented various policies and programs to help reduce emissions and to promote the renewable energy development. Executive Yuan, the executive branch of the government in Taiwan, passed the “Frameworks of Sustainable Energy Policy: an Energy-Saving and Carbon-Reduction Action Plan” in 2008. The target of the plan was to maintain greenhouse gas emissions during the 2016–2020 periods at the 2008 level (284 million tons), to reduce them to the 2000 level in 2025 (256 million tons), and to cut that level in half by 2050 (128 million tons) [6]. Since the promulgation of “Renewable Energy Development Act” in 2009, the Ministry of Economic Affairs (MOEA) has been promoting the development of various renewable energies. The objectives include renewable energy promotion, evaluation of mature technology feasibility, cost-benefit analysis, stages of balance development, domestic industry orientation, and electricity tariff for renewable energy [7]. The geographical environment and resource characteristics are also considered to prioritize the promotion of renewable energy with mature technology and low costs for power generation [7]. In 2010, Taiwan passed the “Green Energy Industry Sunrise Program”, with five major emphases, including technological breakthrough, key investment, environmental molding, export and import, and expanding from within, to lead Taiwan to become a comparable country in the industry of energy technology and production [6,8].

The Ministry of Economic Affairs (MOEA) estimated that the installed capacity of renewable energy would reach 9952 MW by 2025 and further expand to 12,502 MW by 2030 [7]. In fact, at the end of January, 2013, the total installed capacity of renewable energy has reached 3710 MW, consisting of 2081 MW for hydroelectric power, 801 MW for biomass power, 621 MW for wind power and 206 MW for photovoltaic power [7]. The reserve capacities of different types of renewable energy in Taiwan are shown in Fig. 1 [9].

In this study, the current conditions and future prospects of six types of renewable energy in Taiwan are studied, including wind energy, ocean energy, solar energy, biomass energy, geothermal energy and hydropower energy. Some concluding remarks are made in the last section.

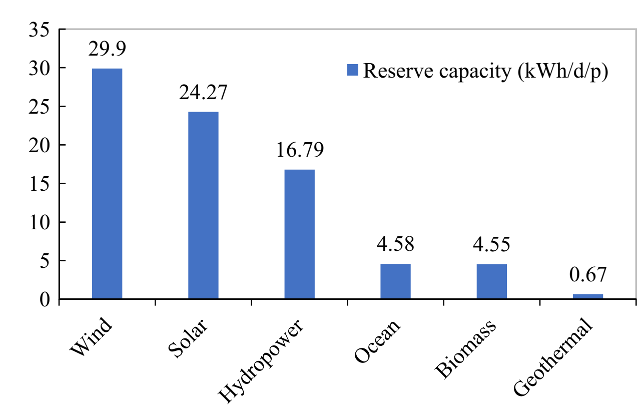

Fig. 1. Reserve capacity of renewable energy in Taiwan [9].

2. Wind energy

Wind power is the conversion of wind energy into a useful form of energy. Wind power, as an alternative to fossil fuels, is one of the cleanest sources of energy. It is plentiful, renewable, widely distributed and clean. In addition, it does not produce greenhouse gas emissions during operations and requires little land.

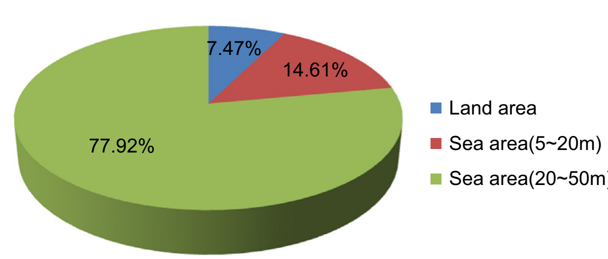

Fig. 2. Reserve capacity percentage of wind energy in Taiwan [12].

In this section, the potentials of wind energy in Taiwan will be discussed first, followed by the introduction of the current situation of wind energy and the wind power industry in Taiwan. The motivation policies and the targets of the government regarding the wind energy will be covered in the last section.

2.1. Potentials of wind energy

Advanced wind power technological progress in the 21st century has reduced the price of wind power in such a way that the wind energy becomes one of the world's fastest growing energy sources [10]. Because of the wind climate in Taiwan, including the Asia monsoons and tropical cyclones during the summer season and the northeast trade winds during the winter season, wind energy could be one of the most promising renewable energy sources in the short term. According to the estimation, the reserve of wind energy is up to 29.9 kWh/d/p (i.e. kWh per day per person), and it is the largest one among six major types of renewable energy in Taiwan [9], as shown in Fig. 1.

According to the statistical report from Industrial Technology Research Institute (ITRI) in Taiwan, a potential of 4.6 GW (7.47%) wind power associated with annual generating hour more than 1800 h is forecasted in areas with wind speed greater than 4.5 m/s as well as wind power density above 150 W/m^2 at 50 m in Taiwan onshore [11]. Based on the analysis of offshore wind power potentials, a potential of 9 GW (14.61%) wind power is predicted while actual amount of 1.2 GW is exploitable in shoal waters of west coast between 5 m and 20 m. In deeper waters between 20 m and 50 m, a potential of 48 GW (77.92%) wind power is estimated while actual amount of 5 GW wind power is exploitable. The composition of wind power potential is shown in Fig. 2 [12]. Since the reserve of wind power in Taiwan is 1.7 times than that of wind-power in developed countries like Denmark and Germany, a great intangible green treasury is observed.

2.2. Current situation of wind energy

Taiwan is an island-based region characterized by narrow land, dense population and almost two-thirds of mountainous areas. The installed capacity of wind energy in Taiwan in each year is shown in Fig. 3 [13]. Nearly 300 units of wind turbines had been equipped in the wind farms on Taiwan land, and their accumulated installed capacity reached 609.6 MW at the end of August 2013 [13]. According to the estimation, the suitable land for wind farms will become exhausted and will be completely exploited before 2020. As its exploitable lands for wind farms are decreasing, Taiwan has planned to transfer land wind energy development to offshore wind energy development. Nevertheless, offshore wind farms are not yet equipped. It is estimated that the maximum number of offshore wind turbines can be around 1000 units, which is equivalent to about 5000 MW of installed capacity.

Developing renewable energy has been a consistent policy of Taiwan government. As stated in White Paper on Energy Industry in 2012, the Ministry of Economic Affairs (MOEA) plans to install the first offshore wind farm by 2015, and develop 1000 MW of shallow-water wind farms, which is equivalent to 200 units of wind turbines, by the end of 2020 [12]. Subsequently, the Ministry will speed up the development of large-scale deep ocean wind farm at an annual rate of additional 200 MW of installed capacity, gradually increasing the accumulative installed capacity to 3000 MW, reaching 600 offshore units and creating 20 billion US dollars of wind power generation by 2030. Targets of offshore wind turbines are shown in Fig. 4 [14].

2.3. Wind power industry

As a clean renewable energy, wind power has gradually attracted wide interests in Taiwanese business. Taiwanese firms will make an investment of over 5 billion US dollars to develop offshore wind power farms [15]. During the first period of the project, 45 million US dollars will be invested (25 million dollars of which will be obtained from budget subsidy for the demonstration project), and 2 units of wind turbines are to be installed by the end

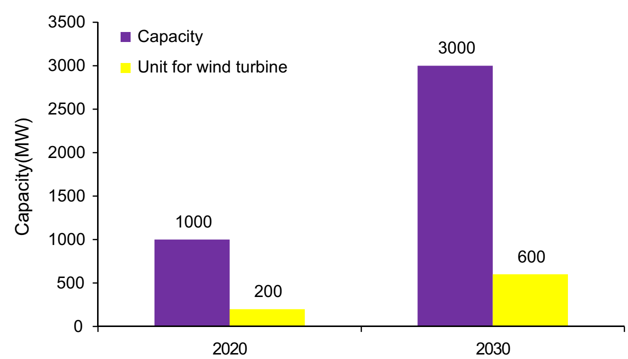

Fig. 4. Primary target of offshore wind turbines in Taiwan [14].

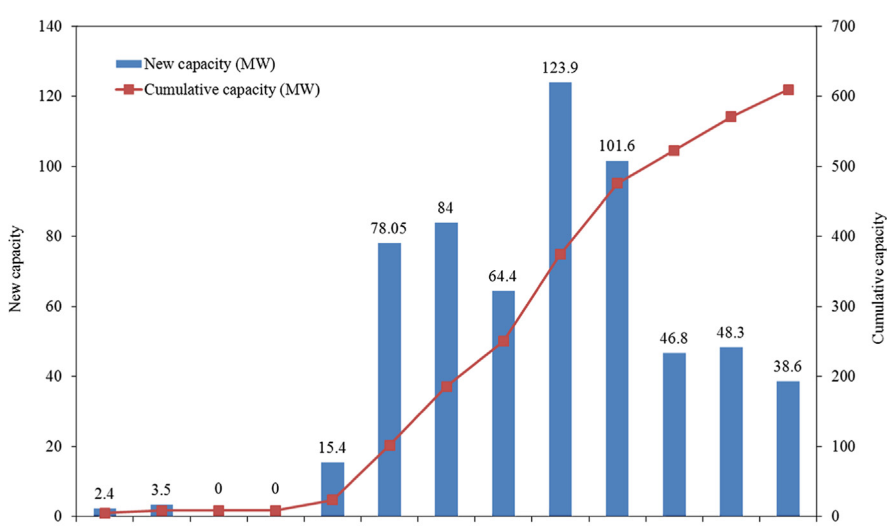

Fig. 3. Installed capacity of wind energy in Taiwan [13].

Table 1
Wind energy capacity and barriers.

Capacity	Year			
	2012 (MW)	2015 (MW)	2020 (MW)	2025 (MW)
Onshore wind turbine	571	866	1200	1200
Offshore wind turbine	0	15	1000	1800
Barriers and difficulties	Offshore wind energy is a new technology and a new trend in development in Taiwan. Therefore, it is a challenge for planning, constructing, and operating offshore wind farms at this stage. Taiwan must learn the experience of wind power development from advanced countries and carefully consider the government policy, the renewable energy laws, standards for renewable energy connection to the system, system impact study, maintenance technology of wind generation facilities and other relevant issues.			

of 2014. During the second period of the project, 4.5 billion US dollars will be invested to install 3 wind farms at sea, totaling 300 units of offshore wind turbines. In recent years, Taiwanese firms have made the transition toward developing and manufacturing key components like the wheel hub castings and bases in the wind power generation industry [16]. Among the top 10 global wind turbine manufacturers, Taiwan firms have established business relationship with 6 system suppliers from Europe and the U.S.A., supplying over 6000 wind turbine hubs ranging from 0.85 MW to 3 MW. Concurrently, Penghu county government plans to establish companies to develop wind farms in Penghu, an archipelago off the western coast of Taiwan in the Taiwan Strait [17].

2.4. Motivation policies

With the generous support and encouragement from the government, Taiwan has shown a booming development in wind power generation market. Executive Yuan released the "Green Energy Industry Sunrise Program" and listed the wind power industry as one of the six emerging industries in 2010. Recently, National Property Bureau of the Ministry of Finance announced that the green-energy industry was expected to be the new trillion US dollars industry by 2015. According to the statistics, the total industrial output values of green energy in 2010 exceeded 12.7 billion US dollars. In the same year, the Ministry of Economic Affairs (MOEA) awarded 1 billion US dollars to encourage the involvement of private sectors to establish demonstration offshore wind power farms, aiming to construct over 1000 units of onshore and offshore wind turbines as well as generate over 30 billion US dollars of wind power industry chain by 2030. The Ministry of Economic Affairs (MOEA) expressed that energy would be an important foundation for Taiwan. The government has been consistently seeking energy for environmental sustainability, and the wind power would be indeed the prime choice. For the purpose of accelerating the development of renewable energy and creating the green energy economy, the Bureau of Energy has launched a promotion office after multilateral efforts and coordination, and this is a significant step for the renewable energy policy. The target of the promotion office is to build millions of solar roofs and thousands of wind turbines.

To promote the development of renewable energy in Taiwan, the government has released a series of preferential policies. The State Bureau of Property has announced the modified version of "Handling Measures on the Application for the Development of State-owned Non-Public Use Lands" on June 4, 2012, encouraging entrepreneurs to engage in the development of public utility like the wind power generation [18,19]. Those intending to involve in the industry can apply from the Ministry of Economic Affairs (MOEA) for establishment preparations, and from the State Bureau of Property for the state-owned non-public use lands. As stated in the "Measures on the Demonstration Awards for the Wind Power Generation Offshore System" released by the Ministry of Economic Affairs (MOEA) in 2012, the Ministry provides 50% of the setup fee as the awards for the demonstration units as well as 8 million US dollars of incentive fees for the demonstration wind farms.

2.5. Targets

Promoting the development of offshore wind farms will definitely facilitate Taiwan to reach the goal of carbon dioxide reduction, adjust low carbon energy structure and prosper the green energy industry. It meets the legislative purpose of "Renewable Energy Development Act": to promote renewable resource utilization, enhance energy diversification, improve environmental quality, motivate related industries and guarantee the sustainable development of Taiwan, as well as constructing a solid foundation for the renewable energy industry in Taiwan. Table 1 summarizes the current and future energy production, barriers and difficulties, of wind energy in Taiwan.

3. Ocean energy

Oceans, which cover more than two-thirds of the surface of the earth, can provide abundant ocean energy. Ocean renewable energy includes tidal power, wave power, current power, salinity gradient power and ocean thermal power. In addition to the immense energy as well as advantages of renewable property and pollution free, the ocean energy resource occupies no land space. Therefore, it is a renewable energy with high potential. In the world, the ocean energy capacity totals about 73.6 billion kW, among which 40 billion kW (54%) is ocean thermal power, 30 billion kW (41%) comes from salinity gradient power, and 3 billion kW (4%) occurs from combined wave, current and tidal power [20,21].

In this section, the potentials of ocean energy in Taiwan will be examined first. The current research and development and three most promising ocean energy sources will be covered, followed by the introduction of the ocean energy industry in Taiwan. The last sections will go over the motivation policies and the targets of the Taiwan government regarding the ocean energy.

3.1. Potentials

Taiwan is surrounded by sea and has coastline of more than 1500 km. International Energy Agency – Ocean Energy Systems (IEAOES) specified the theoretical generation of annual ocean energy as follows: 10,000 TWh of ocean thermal energy, 8000–80,000 TWh of wave energy, over 800 TWh of ocean current energy, above 300 TWh of tidal energy and 2000 TWh salinity gradient energy [22]. Among these ocean energies, the ocean thermal energy, wave and current energy have great potentials for development in Taiwan.

Since the tidal range in Taiwan is small, roughly 3–4 m, tidal power generation has no economic incentives, and the development potential for wave power generation only lies in the northeastern

waters. For the ocean thermal energy, its source is relatively stable but with low efficiency in thermal conversion. To be cost effective, a huge amount of deep ocean water has to be extracted, and the extracted ocean water needs to be utilized for multiple purposes. With the existing planned development scale of deep ocean park, it is still quite difficult to achieve up to 1 MW for the development of the ocean thermal power generation in the near future.

The reserve of ocean thermal power is estimated to be about 30,000 MW, of which 3000 MW is exploitable [23]. The sites suitable for ocean thermal power generation mainly include the open seas off the eastern Hualien and Taitung, and the water temperature at the depth of 1000 m is different from the surface waters by 20 °C. Taiwan has the most abundant wave energy resources, which is about 10,000 MW. The exploitable amount is estimated to be 1000 MW. The open seas off the northeast of Taiwan have the highest potentials to exploit wave energy, and a potential of 10 kW/m is predicted. The waves are even higher in the offshore areas [24]. Although there are abundant wave energy resources, ocean energy still remains relatively unexplored in Taiwan at present due to the fact that technical R&D and special financial support policies are currently not in place. In terms of the ocean current power, according to the statistics of Taiwan Bureau of Energy, Taiwan has a theoretically ocean current available reserve of 3000 MW, with an estimated exploitation amount of 300 MW, as shown in Fig. 5 [25]. Penghu waters, where topographical effect is prominent and Kuroshio is off the east coast of Taiwan, have considerable potentials of ocean current power, and the flow velocity in high-speed Kuroshio regions exceeds 1.2 m/s.

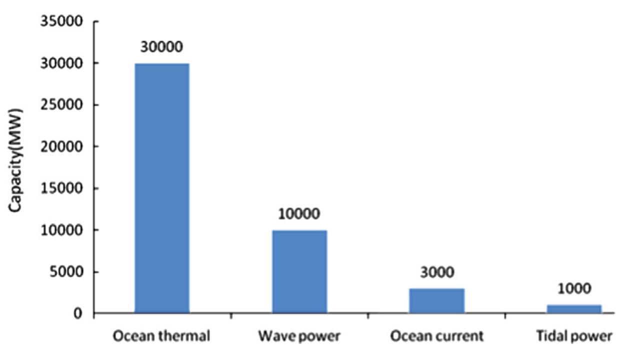

Fig. 5. Reserve capacity for different ocean energies in Taiwan [25].

3.2. Current research and development

Current R&D activities on three kinds of the most promising ocean energies in Taiwan are discussed here.

3.2.1. Wave power

While Taiwan has developed kilowatt wave-activated generator unit, it is speeding up R&D, adopting innovative technologies, and applying for wave power generation related patents in order to keep pace with the international level. By developing wave power generation system suitable for Taiwan's oceanic conditions, Taiwan aims to establish small- and medium-scale wave power generation test site, and improve technologies relating to the power generation system, distribution and maintenance, in order to promote

Table 2
Schedule of technical development of ocean energy [18].

Technology projects	Short term (∼2015)	Medium term (∼2020)	Long term (∼2025)
Wave power generation	Small and medium size system development: • Strengthening the evaluation of ocean/tidal current potential. • Development of technology applicable to ocean/tidal current power generation. • Conceptual technology of Kuroshio power generation system.	Development of large-scale system: • Application demonstration of 100 kW wave power generator units. • Commercialization of 100 kW high-efficiency wave power generator. • Establishment of MW power plant. • Offshore laying operation technology. • Grid connection technology.	Development of commercial power plant: • Technology for building commercial-scale power plant. • Commercialization of wave power generation devices. • International marketing of wave power generation devices.
Ocean thermal power generation	Verification of ocean thermal power generation technology. Small and medium size system development: • Demonstration and promotion of 10 kW low level ocean thermal power generation system. • Development technology for high-efficiency 100 kW low level ocean thermal power generation. • Development of high-efficiency heat exchanger. • R&D of turbine generator.	Development of large-scale system: • Establishment and operation of 100 kW low level ocean thermal power generation plant. • Promotion plan for the establishment of MW OTEC demonstration power plant. • Development of cold water pipe technology. • Development of floating platform. • Development of high-efficiency turbine technology.	Development of commercial power plant: • Develop technology for large-scale ocean thermal energy floating power plant. • Development technology for floating platform.
Ocean current power generation	Ocean current potential assessment technology. Verification of ocean current power generation technology. • Strengthen the evaluation on potential of ocean/tidal current. • Development of technology applicable to ocean/tidal current power generation. • Conceptual technology for Kuroshio power generation system.	Development of large-scale system: • Development, testing and demonstration of Kuroshio power generation system. • Construction technology for deep ocean water projects. • Submarine cable technology.	Development of commercial power plant: • Large-scale power plant development technology. • Development of in-operation service technology.

international cooperations in the development of large-scale products for the international market.

3.2.2. Ocean current energy

Taiwan has established the first real-time reporting and forecasting system for ocean current to evaluate Kuroshio and tidal current energy as well as to provide basis for the evaluation of promotion and development. However, the island is still in the evaluation stage. Despite the existence of bountiful potential of Kuroshio off the east coast of Taiwan, Taiwan faces both great technical difficulty and deficiency of experience. Therefore, the island has to progress steadily. It should give the priority to the development of tidal current power generation, as well as the technology applicable to both Kuroshio and tidal current power generation to lay the foundation for the promotion of Kuroshio power generation. In the future, Taiwan should gradually take efforts to overcome the issues relating to deep ocean, power generation system and power distribution, and to achieve progress in Kuroshio power generation.

3.2.3. Ocean thermal energy

Taiwan has successfully completed the design and development of the first experimental platform and field unit for 5 kW ocean thermal power generation. As a stable energy source, power generated by ocean temperature difference is available all year long. Therefore, the development strategy is to first invest in R&D of key and system technologies concerning the ocean thermal energy generation, then progressively in the utilization of industrial waste heat, terrestrial heat and hot spring to generate power; namely, first developing the domestic ocean thermal energy generation industry, and eventually extending to the exploitation of ocean thermal energy.

The schedule of technical development of ocean energy is summarized in Table 2 [18].

3.3. Ocean energy industry

After laying a solid foundation of basal energy, the R&D of ocean energy should be continuously promoted to narrow the gap with the international technology. In the coming years, in the field of wave power generation, Taiwan intends to proceed with the development of 100 kW wave power generation system after the successful development of 20 kW ocean thermal power generation system [26]. For ocean thermal power generation, the island will promote the R&D of 50 kW and 200 kW ocean thermal power generation system and then extend efforts to waste heat and geothermal power [26]. For the ocean current power generation technology, it is scheduled at the present stage to invest in the analysis of conceptual technology for Kuroshio power generation system as well as the technology applicable to the ocean/tidal current, so as to advance the development of Kuroshio and tidal current power generation. In terms of the overall technical development, ocean energy is designed to develop from Proof of Concept (POF) stage, small and medium size system development stages, to large-scale system development stage, and eventually to the commercialization of power plant, for the purpose of developing ocean energy in large scale.

3.4. Motivation policies

To reach the target of renewable energy development, Energy Commission of the Ministry of Economic Affairs (MOEA), as per the “Renewable Energy Development Act” (2009), encourages and promotes the pollution-free green energy. The commission motivates the renewable energy investors by stipulating that the energy purchase price shall not be lower than the average cost of fossil fuel power generation in Taiwan. In addition, for the renewable energy power generation and utilization system as well as related facilities, depending on different facility features, it is not necessary to apply for miscellaneous licenses in accordance with Building Act when the installed capacity, height or area do not reach a specified scale. Those measures will facilitate the development of industries relating to renewable energy.

3.5. Targets

Developing ocean energy resources will help reduce both energy supply risk and environmental damage. Furthermore, it will facilitate the development of Taiwan ocean industry. In the future, Taiwan is expected to take more efforts in promoting the utilization of renewable ocean energy. Table 3 summarizes the current and future energy production, barriers and difficulties, of ocean energy in Taiwan.

4. Solar energy

Solar energy, which is the radiant heat energy received by the earth from the sun, provides most of the direct or indirect energy in the earth. The average solar energy reaching the top of the atmosphere directly facing the sun is about 1360 W/m^2 [27]. Because the earth is a sphere, the average amount of sunlight reaching the top of the earth's atmosphere is one-fourth of the total solar irradiance, or approximately 340 W/m^2 [27]. For the solar energy reaching the top of the atmosphere, about 29% is reflected back to space, about 23% is absorbed in the atmosphere, and 48% is absorbed by the surface [28]. As a result, about 71% of the solar energy is absorbed by land and oceans. The energy radiated by the sun per hour to the earth is equivalent to the annual consumption amount of traditional energy on the planet.

Table 3
Ocean energy capacity and barriers.

Capacity	Year			
	2012 (W)	2015 (KW)	2020 (KW)	2025 (MW)
Wave power	50	50	500	50
Ocean thermal power	5	5	500	50
Ocean current power	0	500	500	100
Barriers and difficulties	The related technology in Taiwan is still below the advanced countries, and Taiwan needs to accelerate the development and application of innovative technologies, such as the related patents and key technologies for wave, temperature difference, and tidal energy. Wave power systems in Taiwan should be developed. The academia and industry should work together to promote the domestic power generation test field, deployment and maintenance techniques, and then to promote international cooperation in large-scale systems and to market them in the global market. However, the process will encounter a variety of difficulties, including extreme conditions (typhoons, earthquakes), lack of a permanent ocean waters and equipment testing, environmental issues, conflicts of interest (fishing and sailing), legal issues for marine energy development, marine construction capacity, large diameter cold water pipe technology, and development costs.			

In this section, the potentials of solar energy in Taiwan will be introduced first. In Section 2, the PV energy in Taiwan will be presented. The current PV energy capacity and the PV energy industry in Taiwan will be discussed, and the motivation policies of the government will be covered. In Section 3, the solar thermal energy in Taiwan will be introduced. The potential and current situation of the solar thermal energy will be discussed, and the industry will be presented. Finally, the motivation policies of the Taiwan government regarding the solar thermal energy will be covered.

4.1. Potential

Taiwan is located in a subtropical island between the latitudes of 228 and 258 North and the longitudes of 1208 and 1218 East. Due to the benefits of long duration of insolation and small angle of daylight deflection, Taiwan has an average daily sunshine of 3.78 kWh/m^2 and is very suitable for the development of solar energy. Its theoretical reserve of solar power reaches 30,000 MW, of which 300 MW is exploitable at present stage [29]. Tainan and Hengchun, where the longest annual daily sunshine is available, are ideal places for the development of solar energy. Solar energy falls into two major categories: photovoltaic (PV) and solar thermal energy. With respect to solar equipment, solar electric power systems use photovoltaic panels to convert sunlight into electricity, while the solar thermal energy systems use collectors to absorb radiation to produce electricity.

4.2. PV energy

4.2.1. Current situation

A soaring installed capacity of global photovoltaic was observed from 427 MW in 2002 to 6557 MW in 2008, with a compound growth rate of 57.68% [30]. In 2010, the combined production output of solar cell in Taiwan and mainland China has accounted for 60.5% of global output. With the ever-growing photovoltaic industry, the installed capacity in Taiwan skyrocketed from 0.33 MW in 2002 to 222 MW in 2012, as shown in Fig. 6 [13]. According to the latest statistics, the installed capacity of photovoltaic energy in Taiwan has reached 313.34 MW by the end of August, 2013 [13].

4.2.2. PV energy industry

The photovoltaic industry in Taiwan has been equipped with the deliverability in polycrystalline silicon raw material, silicon wafer and sizing materials. Equipment ranging from crystal growth to cell manufacturing and module encapsulation has been localized, and this effectively reduces the industrial external dependence. For the downstream products, due to the growth of domestic market, a new wave of investment has emerged to accelerate the integration of upstream, middle stream and downstream industrial chains.

The future development of Taiwan's PV industry, shown in Table 4, will embark on the acceleration of differentiation technology in the industry, establish new-type cell module technology with independent patents, develop next-generation technology (compound solar cell etc.) and higher value-added industry, for the purpose of making the industry more competitive on a global scale [31]. In addition, since Taiwan has grasped the core technology of semiconductor and display panel industry, Taiwan's large-size enterprises will achieve better industrial integration and occupy more global market share by cooperating with holders of internationally leading technologies [32].

4.2.3. Motivation policies

In 2000, Bureau of Energy under the Ministry of Economic Affairs (MOEA) issued “Measures of Subsidy for Photovoltaic Power Generation Demonstration System Setup” , providing a subsidy up to 50% of total setup fee. In March 2002, “Auxiliary Measures of Subsidy for Photovoltaic Power Generation Demonstration System Setup” was implemented, providing subsidies in full. Furthermore, in 2008, “Auxiliary Operation Implementation Plan for the Construction of Solar Community” was promoted to subsidize public facility and private construction in the solar community. In 2009, “Revitalize Economy by Promoting Public Construction in Photovoltaic Demonstration Setup” was unveiled in a bid to help achieve the target of “Photovoltaic Demonstration Island” [32,33].

In addition, the government has provided finance and tax awards to encourage enterprise involvement in the solar energy industry. In 2010, in order to encourage the introduction of foreign technology, “the Measures for the Application for Exemption of Renewable Energy Power Generation Equipment and for Rendering of Import Tariff Items and Certificates” were implemented to provide import tariff exemption [32,34].

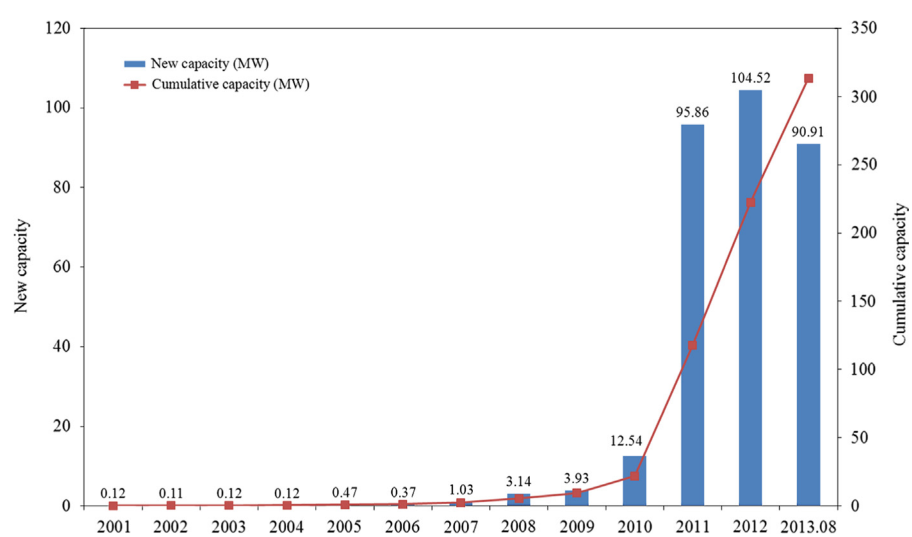

Fig. 6. Installed capacity of solar photovoltaic energy in Taiwan [13].

Table 4
Photovoltaic technology development schedule [30].

Technological item	Short term (~2015)	Medium term (~2020)	Long term (~2025)
Solar cell	• Component of battery: – Efficiency for 1 cm × 1 cm: 14% (Thin-film silicon) – Efficiency for less than 1 cm × 1 cm: 22% (CIGS) • Module: – Efficiency for 55 cm × 70 cm: 9% (Thin-film silicon) – Efficiency for 60 cm × 120 cm: 15% (CIGS) – Efficiency for 10 cm × 10 cm: 9% (Dye-sensitized) • Technological development of large-sized thin-film silicon TOC glass • Life-span of 3–5 years for dye-sensitized solar cell, with 9% efficiency	• Component of battery: – Efficiency for 1 cm × 1 cm: 16% (Thin-film silicon) – Efficiency for less than 1 cm × 1 cm: 25% (CIGS) • Module: – Efficiency for 55 cm × 70 cm: 12% (Thin-film silicon) – Efficiency for 60 cm × 120 cm: 20% (CIGS) – Efficiency for 10 cm × 10 cm: 11% (Dye-sensitized) • Life-span of 5–10 years for dye-sensitized solar cell, with 11% of efficiency	• Component of battery: – Efficiency for 1 cm × 1 cm: 17% (Thin-film silicon) – Efficiency for less than 1 cm × 1 cm: 30% (CIGS) • Module: – Efficiency for 55 cm × 70 cm: 14% (Thin-film silicon) – Efficiency for 60 cm × 120 cm: 25% (CIGS) – Efficiency for 10 cm × 10 cm: 15% (Dye-sensitized) • Life-span of 20 years for dye-sensitized solar cell, with 15% of efficiency
PV systems	• Popularization of PV system technology • Construction of standardized PV system • Promotion of the use of qualified components • Research of low setup cost • Research of system reliability • Research of system maintenance and management • Research of the integration of the composite function of building-integrated photovoltaics (BIPV) with buildings structure	• Stabilized and safe PV system technology • Standardization of the specifications of components • Research of expert maintenance management for large-scale or high quantity system • Integration of large-scale PV system and large-scale energy storage system • Forecasting research of regional PV system outputs • Application research of the composite function of BIPV	• PV system technology for independent operations • Installation of home appliances and promotion of maintenance system • Research of island-type PV power supply system • Research of regional PV electric power supply system • Research of stabilized power supply of large-scale PV system

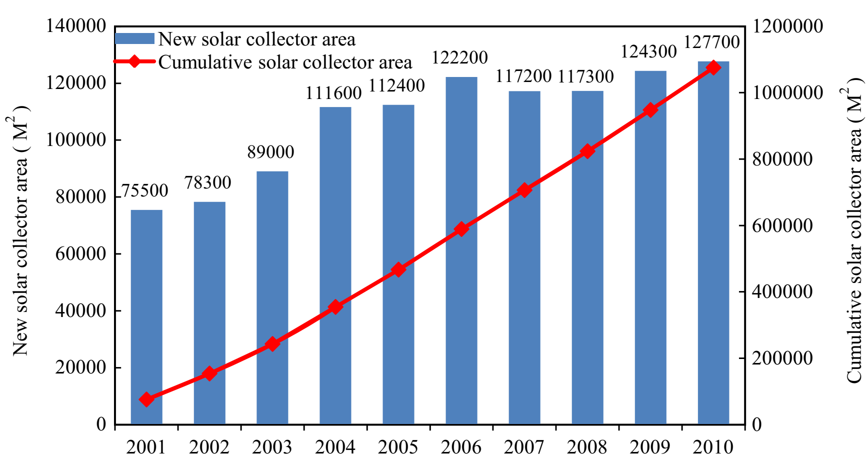

Fig. 7. Installed solar collector area in Taiwan [34].

4.3. *Solar thermal energy*

4.3.1. *Potential*

Annual sunshine in Taiwan is in a range of 1500–2200 h for most parts of the island, and even reaching 2500 h in the southernmost region. As the average solar irradiance in Taiwan is 716–1027 kcal/daym^2, solar energy resources in Taiwan are abundant to make the development of solar energy extremely practical compared to most of other locations around the world.

4.3.2. *Current situation*

With the strong support and promotion from Taiwan government, the installed solar thermal collector in recent years has maintained a steady growth. According to the statistics, 500,000 households had installed solar water heaters by the end of 2010, up to 127,700 m^2, and a total solar collector area of 1,924,300 m^2 is predicated, as shown in Fig. 7 [35]. Both the popularizing rate (6.5%) and density of the setup area (52.82 m^2/km^2) make Taiwan rank the fifth in the world. For the solar thermal utilization, it is mainly based on the development

of collector and design of small-size home system, while non-domestic large-scale system accounts for only 1.6% of the total installed areas [19].

4.3.3. Solar thermal energy industry

As the sunshine diffusion in Taiwan is relatively high, Stirling power generation system (small-sized solar thermal system featuring Fresnel lens distributed heating collection) will be the dominating development. At present, the island has installed the process equipment for medium temperature solar energy selective absorption film. Such equipment has the service temperature as high as 300 °C. Next step is to design high temperature solar energy selective absorption film operating as high as 500 °C. As a result, the thermal energy conversion efficiency of Stirling engine will be significantly improved. Another development orientation is aimed at the combination of solar thermal collector and building. Currently, some frameworks such as embedded types of solar thermal collectors have now been integrated with pitched roof, parapet wall and canopy of buildings. Buildings integrated with solar thermal collector technology should be carried out in the future to establish the complete technical development system. The future development schedule for solar thermal energy technology is shown in Table 5 [36].

4.3.4. Motivation policies

The government's supportive policy aims to reward the setup of solar water heating system to promote the utilization of solar thermal energy. Since 2009, the Ministry of Economic Affairs (MOEA) has put forth "Measures of Award for the Promotion of Solar Water Heating System and Relevant Operations" to encourage the installation and utilization among the public. On June 12, 2009, "Renewable Energy Development Act" was passed. On July 8, 2009, the "Measures on Award and Subsidy for the Utilization of Solar Thermal Energy" were formulated in accordance with the former "Measures of Award for the Promotion of Solar Water Heating System" and then implemented on April 12, 2010, aiming to reach the government target of popularizing the solar energy as well as to push the development of solar energy in Taiwan. Table 6 summarizes the current and future energy production, barriers and difficulties, of solar energy in Taiwan.

5. Biomass energy

In this section, the current biomass energy generation in Taiwan will be introduced, and the future development and government policies for the biomass energy will be covered.

Biomass is the first energy source harnessed by mankind. It had been the primary energy source for more than half of the world's population, accounting for 14% of the total energy consumption in the world [37]. Currently, biomass is the fourth largest energy source in the world after coal, petroleum and natural gas. Biomass is one of the renewable energy sources on which policy makers are greatly dependent since a flexible feedstock can be converted into electricity, transport liquid fuels and heat by chemical and biological processes on demand [38].

Biomass energy is mainly utilized in three aspects: biomass power generation, biodiesel utilization and the development of bio-hydrogen technology. For biomass energy, 1.12 billion kWh of

Table 5
Solar thermal energy technology development schedule [36].

Technological item	Short term (~2015)	Medium term (~2020)	Long term (~2025)
Technology upgrading and promotion of solar water heaters	• Mass production and technological upgrading of sputter-deposited selective absorber coating • High performance of sprayed selective surface absorber coating	• Promotion and application of high-performance absorber coating • Establish international product certification	• Develop new solar hot water generation equipment by integrating building and solar thermal cooling system
Technology upgrading and promotion of solar thermal air conditioning	• Research and development of thermal collector technology of solar thermal-assisted cooling system • Research and development of solar thermal-assisted ventilation system	• Technology upgrading and application of medium temperature solar collector • Technology development of heat storage of solar thermal cooling system • Technology upgrading of solar thermal ventilation system	• Demonstration and promotion of solar thermal ventilation system • Develop air-conditioning equipment that integrates with building
Technology integration and promotion of solar thermal energy and building	• Research of the structure safety of solar water heating system • Technology development of architectural and synchronous design of solar water heating system	• Building material and standardization of new solar collectors	• Application technology development of multi-functional solar thermal system • Demonstration and promotion of multi-functional building integration system

Table 6
Solar energy capacity and barriers.

Capacity	Year			
	2012	2015	2020	2025
PV power	222 MW	750 MW	1500 MW	2500 MW
Solar thermal power	2.1 MM^2	2.8 MM^2	3.6 MM^2	4.09 MM^2
Barriers and difficulties	While Taiwan's export of solar cells and OEM/ODM modules is significant, the key technology and system services are still substandard compared to those of more advanced countries. It is necessary, through policies and incentives, to accumulate the technology and experience of systems in the upstream, midstream and downstream aspects of the industry, promote domestic demand, increase capacity utilization, and promote a balanced market.			

annual potential, which is equivalent to 460,000 t of coal, is estimated. For biodiesel, Taiwan currently maintains 502,000 ha of arable lands, and a potential of 300,000–400,000 t of vegetable oil is estimated. A production evaluation of many biodiesel crops in Taiwan shows that the output of these biodiesel crops is low, price of the raw materials is high, and total production cost is relatively high [39]. Oppositely, biodiesel crops can revitalize agriculture and prosper the country economy. Fallow farmlands, estimated about 220–250 thousand hectares every year, can be utilized effectively, agricultural employment opportunity can be promoted, and peasants' lives can be improved [40]. Bio-hydrogen technology has a great potential for exploitation. With a 10% hydrogen conversion capability, there is a potential of 26 MW from industrial waste water in Taiwan [19].

Statistics showed that the installed capacity of biomass energy in Taiwan was 740.4 MW in August 2013, as shown in Fig. 8 [13]. However, it is estimated that the potential of biomass power can reach 1030 MW by year 2015. The reserves of biomass energy from urban and industrial waste can provide Taiwanese with energy of 0.36 kWh/d/p, equivalent to the electric energy of 0.144 kWh/d/p. Furthermore, it is practicable to expand the utilization of biomass energy by utilizing other available biomass materials, such as agricultural waste and forest waste. These alternative reserves of biomass energy can provide Taiwanese with energy of 3.29 kWh/d/p, equivalent to the electric energy of 1.316 kWh/d/p [28]. To promote the production and application of regional solid derived wastes, the government provides an investment opportunity in biomass energy industry worth over 1 billion US dollars, and this will significantly improve the social economy and foster the application of renewable biomass energy [19].

For the development of biodiesel and bio-hydrogen technology, it is recommended to integrate energy crop planting with the green city concept to build up demonstration systems, which can promote the utilization of the fallow or idle cultivated lands for energy crop. However, Taiwan has no bioethanol manufacturer since the price of starch or sugar for alcohol production is higher than that of the imported alcohol. Therefore, Taiwan still adopts the imported alcohol at the current stage of the demonstration

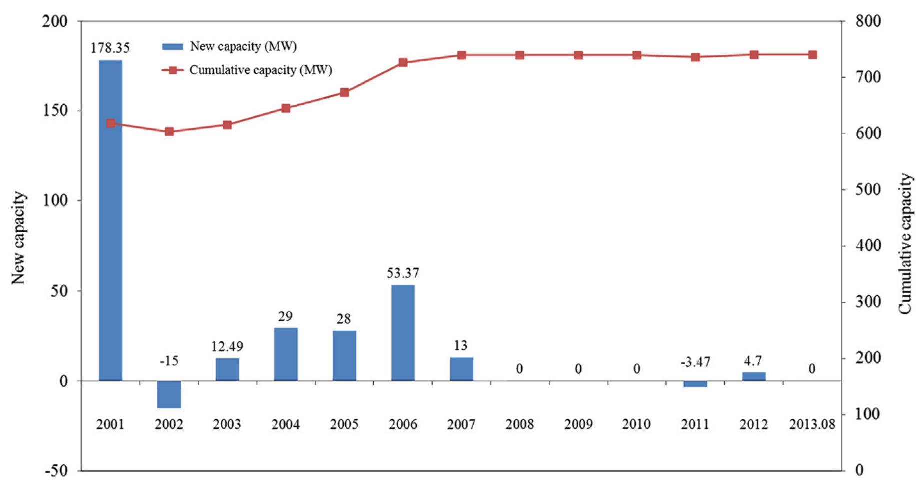

Fig. 8. Installed capacity of biomass power in Taiwan [13].

Table 7
Biofuel technology development schedule [18].

Technological item	Short term (~2015)	Medium term (~2020)	Long term (~2025)
Thermoelectric use of biofuels	• Technology for preventing high-temperature corrosion for boiler • Technology for combustion optimization for boiler • Technology for biomass torrefaction • Fast pyrolysis process for wastepaper slag discharge • Composite bioenergy demonstration systems	• Biomass integrated gasification combined cycle (BIGCC) technology, power generation efficiency > 40% • Bioenergy purification and power generation technology, hydrogen rate > 30 m^3/m^3/day	• Biomass integrated gasification combined cycle (BIGCC) technology, power generation efficiency > 50% • Bioenergy purification and power generation efficiency, hydrogen rate > 50 m^3/m^3/day • Commercialization of composite biomass systems
Biodiesel technology development	• Technology development for high purity glycerol recycling, 99% purity • Biological transesterification, 90% yield rate • Biodiesel annual energy capacity reaches 250,000 kiloliters	• Biodiesel annual energy capacity reaches 350,000 kiloliters • Operation of high purity glycerol recycling plant, annual energy capacity reaches 10,000 kiloliters • Process integration and development of Microalgae oil production	• Biodiesel annual energy capacity reaches 450,000 kiloliters • Improvement of high purity glycerol recycling plant, annual energy capacity reaches 20,000 kiloliters • Energy crop area of 200,000 hectares • Microalgae cultivation capacity reaches 60 g/m^2/day
Bioethanol technology development	• Bioethanol annual energy capacity reaches 300,000 kiloliters • Supply for metropolitan area	• Bioethanol annual energy capacity reaches 400,000 kiloliters • Full-scale supply	• Bioethanol annual energy capacity reaches 500,000 kiloliters • Full-scale supply

project, and plans to consume 300,000 kiloliters of bioethanol by 2015 through promotion activity. At present, Taiwan government has made substantial investments to develop cellulose ethanol technology for the purpose of producing cellulose ethanol competitively, and the aims are to meet the existing demands as well as create greater industry values [19]. Based on the planned schedule, an annual biodiesel output of 250,000 kiloliters in Taiwan is predicted by 2020. This is worth 8 million US dollars, and up to 4.5 million US dollars is to be invested. In the same year, biomass power generation will reach 850 MW while an output value of about 45 million US dollars is estimated. In addition, National Science Council has promoted the implementation of the "National Energy Technology Program" and embarked on seven biomass energy research projects: bioethanol, biodiesel (crop), biodiesel (alga) methane, biomass pyrolysis oil, biomass butanol, biomass hydrogen and biomass power [19]. The future development schedule for biofuel technology is summarized in Table 7 [18].

The main sources of methane in Taiwan are waste-based, including livestock wastewater (pig manure and urine), domestic wastewater (wastewater treatment plant), landfill, and industrial waste disposal. Current methane production is of small scale and cannot become pipe-line gas. The electricity generation is by direct combustion, and the power is used in places such as small and medium-sized farms for heat lamps and textile factories for auxiliary boiler fuel, etc. In recent years, methane fermentation technology is applied in landfill gas to generate electricity. Since 1997, the Environment Protection Administration in Taiwan has invested NT $2.1 billion to promote the "restoration and reuse plan for closed waste sanitary landfill". Up to 2013, 159 landfills have been successfully restored. The first landfill with biogas recovery and power generation is in Sanxia District, New Taipei City, which is located in the north of Taiwan. The first landfill with biogas based power generation in middle Taiwan is in Taichung. It has four generators, which can handle 25.5 million m^3 of biogas annually, equivalent to a reduction of 15,100 t of methane emissions, and 5448 kW of power can be supplied to 7000 households.

Table 8 also summarizes the current and future energy production, barriers and difficulties, of biomass energy in Taiwan.

6. Geothermal energy

In this section, the geothermal resources in Taiwan will be introduced, and the development potentials of geothermal energy in Taiwan will be presented.

Taiwan is located on an orogenic collision belt between the Philippine Sea Plate and the Eurasian Plate, and the land is easy to squeeze and collide, making the occurrence of earthquake particularly frequent. In addition, the geology formation is also prone to faults and folds, and thus rock layers are constantly uplifted and broken. Furthermore, since rock is a material of low thermal conductivity, heat dissipation is not easy. With the constant uplift of formation and geothermal accumulation in the long term, there is high geothermal gradient resulted in the area of Central Mountain Range. Additionally, in northern and eastern Taiwan, large-scale volcanic activity has occurred. At present, although the volcanic activity is suspended, hot magma is still reserved under volcanoes. Taiwan is located at the edge of West Pacific Ocean, with the influences of northeast monsoons in winter and southwest monsoons and typhoons in summer. The average rainfall each year is 2500 mm and above. After rain falls down to ground, water flows along fissures or broken rock into ground and is heated by geothermal gradient or hot magma, resulting in rich geothermal resources. Hot spring is an important feature of a geothermal system. Thus, the development potential of geothermal in Taiwan is promising [28].

The only two volcanic geothermal systems in Taiwan are at northern Mt. Tatun and Yi-lan, while others are mostly located in the metamorphic rocks areas of Central Mountains (such as Nan-Tao) and a few located in the sedimentary rocks area of western foothills belt (such as Taidong). There are a total of 26 geothermal resources in Taiwan [41]. Most resources are shallow water-based geothermal systems with non-volcanic nature, and the only volcanic geothermal system is the Mt. Tatun. Mt. Tatun is the geothermal area with the highest potential, but unfortunately, the corrosion problems existing in produced acidic water are yet to be resolved, so its development has been temporarily suspended. The scales of non-volcanic and water-based geothermal areas are small, each reserving a maximum potential of only about a few million watts, suitable for the development of small and medium scales. Nowadays, the cost of using geothermal energy to generate electricity is still high. Nevertheless, geothermal energy can be applied in multiple functions including recreational spots, swimming pool, greenhouse horticulture and agriculture, air conditioning and so on, for the purpose of extracting additional economic value. On the other hand, to avoid the gradual depletion of geothermal resources and prolong the operating life, most hot water can be imputed back to geothermal reservoirs [38]. Taiwan started the exploration of geothermal resources since 1976, and successfully completed the first geothermal power plant, Chingshui geothermal power generator with 3 MW of the installed

Table 8
Biomass energy capacity and barriers.

Capacity	Year			
	2012	2015	2020	2025
Biomass power (urban waste) (MW)	622.5	850	1030	1500
Biomass power (biogas) (MW)	24.5			
Biomass power (agricultural waste) (MW)	167			
Uses of biodiesel (kL)	70,000	250,000	35,000	45,000
Uses of biomass ethanol (kL)	0	159	30,000	50,000
Barriers and difficulties	Currently, the structure of cellulose is too close to be dispersed or hydrolyzed, and it is also surrounded and protected by half-cellulose and lignin. These make the hydrolysis more difficult. Therefore, physical or chemical means must be used to break up the ignocellulose structure, and this will increase the costs. Enzymes with higher conversion efficiency are needed for the saccharification and hydrolysis of cellulose. Because the reaction efficiency is low and the cost is high, current enzymes cannot meet the needs of large-scale production. In order to obtain economic benefits, production technology of enzyme should focus on efficiency improvement and cost reduction. The promotion of technology strategy and development schedule should focus on the screening of the application-based technical analysis, rather than focusing on the development schedule of each kind of technology. With the existing government policies, such as the increase of the proportion of renewable energy, the development of domestic energy, waste treatment, agricultural reuse, carbon dioxide emissions reduction, domestic R&D and industrialization of biomass energy technology can be promoted.			

capacity, in 1981. However, the pilot power plant was halted because of the declination of the output of power generation to unacceptable levels in 1993 [42]. Now, it is serving as a demonstration park for the utilization of geothermal energy for recreation and tourism. A comprehensive exploration estimates that Taiwan has a total geothermal potential of up to 1000 MW [39,41]. The future development schedule for geothermal technology is shown in Table 9 [35]. However, most of the geothermal resources in Taiwan are located in remote areas, making their exploitation difficult. The economically and technically feasible exploitation potential is only about 150 MW. Table 10 summarizes the current and future energy production, barriers and difficulties, of geothermal energy in Taiwan.

7. Hydropower

In this section, the current situation of hydropower and the future development of the hydroelectric generation in Taiwan will be presented.

The average annual rainfall of Taiwan is about 800 million tons with hydropower potential of about 25,700 MW, equivalent to 6.17×10^8 kWh per day or 26.82 kWh/d/p. If the mechanical efficiency of water turbine is about 90%, the maximal electricity available per day per person is about 24.14 kWh/d/p [38]. The population of Taiwan is mostly concentrated in the region with height between 0 and 100 m. If this area is deducted from the calculation procedure, then the daily maximum of hydroenergy available in Taiwan is 23.99 kWh/d/p, and it is reduced to 16.79 kWh/d/p if the evaporation of about 30% is considered. The theoretical hydropower mainly originates from 76 rivers. Due to natural constraints, only 30 important rivers were selected to investigate the technical feasibility of hydropower. The existing total installed capacity is 1900 MW, accounting for about 5% of the total amount of power generation in Taiwan [38]. The statistics showed that the installed capacity of hydroelectric generation in Taiwan was 2081.3 MW in 2012, while the installed capacity still remained unchanged by August 2013, as shown in Fig. 9 [13].

Hydropower is a widely exploited and utilized renewable energy. Hydroelectric generation, which is equipped with simple and complete relevant technologies and has less environmental impact, can provide low-cost power, supply irrigation water, control flooding and perform power dispatching on peak hours [43]. Regarding the hydroelectric generation facilities, since the development of reservoir has been fully saturated, leaving little room for further utilization, the future development of hydroelectric generation should focus on small and medium sized turbines. Table 11 summarizes the current and future energy production, barriers and difficulties, of hydropower in Taiwan.

Table 12 shows the expected CO_2 emissions and barriers for CO_2 emissions reduction in Taiwan.

8. Conclusions

A major development trend to combat global climate changes is energy conservation and carbon reduction. Many countries are vigorously promoting low-carbon economy with high efficiency and low emission, actively developing low carbon technology, and devising industrial, energy, technology, trade policies to develop green industries. The energy resources in Taiwan are not abundant; however, the country has excellent research and development technologies and manufacturing capabilities. Therefore, to promote a low-carbon economy and to compete in international green industries, Taiwan should utilize its characterized technologies and advantages effectively. By focusing on the opportunities of new energy supply and demand system and newly developed industries, Taiwan can achieve low carbonization and maximization of industrial values.

Table 9
Geothermal technology development strategic planning [35].

Technological item	Medium term (~2015)	Long term (~2025)
Geothermal energy technology development	• Production monitoring technique of reservoir • Continue to promote the subsidy measures for the geothermal power exploration • Formulate subsidy measures for power generation equipment	• Establish comprehensive geothermal information • Exploration and development of volcanic geothermal resources • Potential assessment of deep geothermal energy
Geothermal power generation and multiple usages	• Build geothermal power generation demonstration plant • Production capacity optimization • Planning and preliminary design of power plant	• Promote multiple usages • Usages of other geothermal energy

Table 10
Geothermal energy capacity and barriers.

Capacity	Year			
	2012	2015	2020	2025
Geothermal power	1.5 MW	4 MW	66 MW	150 MW
Barriers and difficulties	The development of geothermal power has paused for more than two decades in Taiwan, resulting in extremely limited development of related technologies. To promote the geothermal power in a short time, the fundamental key technologies need to be developed promptly, and the old water renewable cogeneration plant should be regenerated. In the short term, shallow geothermal reserves should be focused on the areas with significant geothermal signs. In the long term, deep geothermal reserves should be focused. However, proper mediator may be lacking for bringing out the heat to the surface, and technology such as enhanced geothermal system (EGS) is required. This kind of technology is not yet mature in Taiwan. Since the mountains in Taiwan belong to the geology of volcano, a detailed survey of deep geology and comprehensive assessment of engineering feasibility are necessary. Regarding the geological engineering and plant engineering, the cost and technology aspects are not promising for land with a depth more than 2 km. For earthquake fault zones, the issues, such as engineering reliability, construction safety, maintenance-and-operation, still need to be assessed comprehensively.			

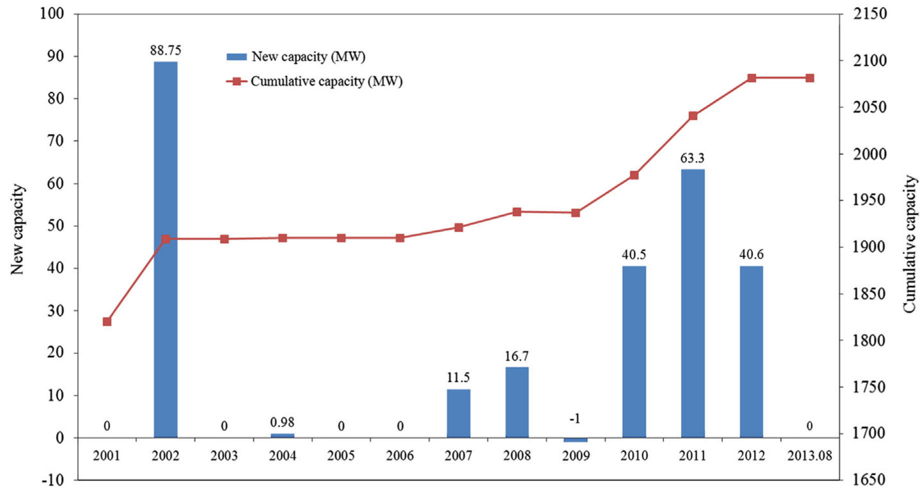

Fig. 9. Installed capacity of hydropower in Taiwan [13].

Table 11
Hydropower capacity and barriers.

Capacity	Year			
	2012	2015	2020	2025
Hydropower	2081 MW	2300 MW	2500 MW	2500 MW
Barriers and difficulties	Taiwan has about 5000 MW of technically feasible hydropower potential, and about half of it is considered economically viable. Around 2500 MW may be exploited by 2020. However, due to the ecological and environmental issues for large-scale dam construction, obstacles for large-scale hydropower development are present.			

Table 12
CO_2 emissions and barriers.

Mt	Year			
	2012	2015	2020	2025
CO_2 emissions	323 Mt	275 Mt	284 Mt	256 Mt
Barriers and difficulties	The lack of energy reserves in Taiwan results in an extremely high dependence on imported energy. Various policy measures are needed to stabilize energy supply and suppress carbon dioxide emissions, in order to meet the carbon reduction requirement and to prevent global trade barriers. The government should strengthen energy conservation, improve energy efficiency, increase the use of renewable energy, and develop energy with low-carbon emissions. Carbon dioxide capture and storage technologies are important means to reduce emissions. However, these technologies are not yet mature and are possessed by certain developed countries. How to cooperate with international firms to develop the technologies and to develop an independent industry is a challenge.			

8.1. Supply and demand system for new energy

On the demand side, the government should build a smart and convenient living environment with energy conservation and carbon reduction. These include intelligent and convenient transportation networks, green buildings, energy efficiency and green energy infrastructures, and low-carbon communities and cities. In addition, a complete market mechanism and legal system foundation for energy conservation and carbon reduction should be built, including “energy tax law” and “greenhouse gas reduction law” so that the external cost can be internalized and carbon reduction ability can be enhanced. On the supply side, the government should strive to promote the “Thousand Wind Turbines” and “Million Solar Rooftop Program” projects, with a total renewable energy device capacity accounted for more than 30% of total energy capacity in 2030. Meanwhile, low-carbon natural gas should be promoted to ensure safe power supply, and smart grid and high-efficiency power system should be constructed.

8.2. Opportunities for new industries

The green energy industries in Taiwan are in its early stage, and they need to possess critical technologies and innovation technologies for future development and competitiveness. Institute for Management Development (IMD) ranked the green technology competitiveness of 58 countries, and Taiwan was ranked the sixth [44]. However, to face the vigorous international competitiveness, Taiwan needs to continue strengthening its research and development and innovation, mastering niche technology, and improving competitiveness. For the development of the emerging green energy industries, the past practice as an export processing country should be abandoned, and the past development pattern which has lacked independent intellectual property should not be adopted anymore. Instead, an industrial model of actively developing critical technologies is necessary. The industries should not adopt the current practices of OEM and ODM. On the contrary, the integration of the industry chain should be strengthened, and a development strategy that shifts from the

manufacturing of simple key components to a vertical integrated system should be adopted. Thus, creating value, instead of creating output, is stressed, and the international competitiveness of the green energy industries can be enhanced.

8.3. Favorable types of renewable energy sources

Developing renewable energy in Taiwan can secure national energy supply and achieve environmental protection and sustainability objectives. The planning of renewable energy development in Taiwan has four sequential stages: research, demonstration, promotion, and prevalence. Current strategies for developing major renewable energies in Taiwan are as follows: (1) Wind energy – promotion phase; (2) PV energy – incentive and demonstration phase; (3) Solar thermal energy – incentive and promotion phase; (4) Biomass energy – research and demonstration phase; and (5) Geothermal energy – research and demonstration phase.

The "Renewable Energy Development Plan" has established a negotiating mechanism among higher governmental levels, so that non-technical barriers can be removed and a more advantageous circumstance can be created. Based on the "Renewable Energy Development Bill" , related renewable energy regulations and legislation, such as fixed feed-in tariffs, grid connection standards and subsidy systems, have been and will continuously be introduced. It is expected that renewable energy will be competitive in the Taiwanese market in the near future. Even though not every kind of renewable energy may be appropriate in Taiwan, the related industrial development may offer positive economic benefits to some sources, which have been described intensely in this work. Energy sources, such as solar thermal energy, photovoltaics, and wind energy, already have formatively industrial bases in Taiwan, and are the most promising sources.

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